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Green supply chain management, agility, and resilience in Mexican manufacturing companies

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Abstract

The objective of the work is to analyze how green supply chain management practices influence the environmental and financial performance of Mexican manufacturing firms, considering supply chain agility and resilience as key organizational capabilities for adaptation in dynamic environments. The methodology consisted of an empirical, quantitative, and cross-sectional study applied to 270 manufacturing companies in Mexico, using a structured questionnaire and Partial Least Squares Structural Equation Modeling (PLS-SEM) to test the proposed relationships among the constructs. The results show that green supply chain management practices have a positive and significant effect on both environmental and financial performance, while supply chain agility and resilience act as important mediating mechanisms that strengthen these relationships. Additionally, big data analytics enhances the impact of green practices on environmental performance, although its moderating effect on financial performance is not statistically significant. It is concluded that the integration of green supply chain management with dynamic capabilities such as agility, resilience, and data-driven decision-making enables manufacturing firms to respond more effectively to environmental pressures, improve sustainability outcomes, and maintain competitiveness within the Mexican industrial context.

Keywords: green supply chain management; agility; resilience; manufacturing industry.

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Gestión verde de la cadena de suministro, agilidad y resiliencia en empresas manufactureras mexicanas

Resumen

El objetivo del trabajo es analizar cómo las prácticas de gestión de la cadena de suministro verde influyen en el desempeño ambiental y financiero de las empresas manufactureras mexicanas, considerando la agilidad y la resiliencia de la cadena de suministro como capacidades organizacionales clave para la adaptación en entornos dinámicos. La metodología consistió en un estudio empírico, cuantitativo y de corte transversal aplicado a 270 empresas manufactureras en México, utilizando un cuestionario estructurado y el Modelado de Ecuaciones Estructurales mediante Mínimos Cuadrados Parciales (PLS-SEM) para poner a prueba las relaciones propuestas entre los constructos. Los resultados muestran que las prácticas de gestión de la cadena de suministro verde tienen un efecto positivo y significativo tanto en el desempeño ambiental como en el financiero, mientras que la agilidad y la resiliencia de la cadena de suministro actúan como mecanismos mediadores importantes que fortalecen dichas relaciones. Adicionalmente, el análisis de big data potencia el impacto de las prácticas verdes sobre el desempeño ambiental, aunque su efecto moderador sobre el desempeño financiero no resulta estadísticamente significativo. Se concluye que la integración de la gestión de la cadena de suministro verde con capacidades dinámicas como la agilidad, la resiliencia y la toma de decisiones basada en datos permite a las empresas manufactureras responder de manera más eficaz a las presiones ambientales, mejorar los resultados de sostenibilidad y mantener la competitividad en el contexto industrial mexicano.

Palabras clave: gestión verde de la cadena de suministro; agilidad; resiliencia; industria manufacturera.

1. Introduction

Global supply chains are responsible for a large share of the carbon emissions and environmental impacts generated by industrial production, including air and water pollution, land degradation and loss of biodiversity (Bové & Swartz, 2016). This situation has increased the pressure on manufacturing firms to adopt cleaner and more efficient ways of operating that balance environmental responsibility with economic results. In response, many companies have strengthened their corporate social responsibility and environmental commitments in order to meet the expectations of customers, investors and regulators (Shafique et al., 2017; Zhu et al., 2005). At the same time, competitive and regulatory forces push organizations to reduce waste and improve the performance of their supply chains (Shultz & Holbrook, 1999), encouraging the adoption of green practices in purchasing, production and logistics (Kouhizadeh & Sarkis, 2018). Under these conditions, environmental pressures have been intensified and firms are looking for strategies that minimize the negative impacts of their products and services while protecting or improving their financial performance (Chan et al., 2016).

In Mexico, manufacturing firms operate within a complex supply chain reality, where traditional practices still dominate and alignment with green supply chain principles remains limited. Although some companies have begun to incorporate environmental actions into their production and logistics processes, these efforts are often partial, reactive, or driven mainly by regulatory compliance or pressure from international markets. Structural barriers such as financial constraints, lack of specialized training, limited access to clean technologies, and weak coordination among supply chain actors continue to hinder the full adoption of green practices. This situation reveals a clear gap between current supply chain practices in Mexican manufacturing firms and the sustainability standards promoted at the global level, highlighting the importance of examining this reality as the core problem of the study.

In this global context, it is particularly important to analyze how Green Supply Chain Management (GSCM) practices can be adapted to the manufacturing sector in Mexico, which faces challenges such as regulatory compliance, international competition, and the shift toward more sustainable business models. Understanding these dynamics helps explain why Mexican firms are under increasing pressure to modernize their supply chain practices.

The concept of GSCM has gained relevance over the last two decades as a management approach aimed at incorporating environmental criteria into supply chain operations (Gera et al., 2022). It supports firms in improving their sustainable performance by integrating ecological, social, and economic considerations from the sourcing of materials to the delivery of finished products (Antwi et al., 2022).

In practice, GSCM encourages cleaner production processes, more efficient logistics, and the adoption of materials and technologies that reduce emissions and waste. These efforts help manufacturing firms strengthen their environmental and operational outcomes (Albort-Morant et al., 2016). Prior studies show that the manufacturing sector has been central to GSCM research, largely because its activities often involve significant environmental and social impacts (Kalyar et al., 2020).

Likewise, Zeng et al., 2022 highlight that operational effectiveness is significant, followed by environmental sustainability, with productivity ranking as the least influential factor. Therefore, managers should arrange governance and environmental factors over immediate profit. In contrast, some studies also concluded that GSCM practices positively influence EP but not FP (Laari, 2018). Similarly, Ahmed et al. (2020) proposed that internal GSCM and institutional forces negatively impact economic performance but significantly contribute to improving eco-friendly performance. In addition, Agyabeng-Mensah et al., 2020 revealed that adopting internal GSCM negatively affects firms' market and FP.

These contrasting findings highlight the need for additional research to clarify the conditions under which GSCM contributes to environmental and financial outcomes. In particular, few studies have examined the role of supply chain resilience (SCR) and agility (SCA) as mechanisms that may strengthen or explain these relationships, or the extent to which big data analytics (BDA) can moderate their effects.

Recent researches have begun to explore these dynamics. Ghaderi et al. (2024) report that GSCM is closely linked to both resilience and agility, while Zhu and Wu (2022) show that resilience can indirectly enhance both environmental and financial performance. Agility has also been associated with improvements in customer satisfaction, operational efficiency, and green innovation (Mirghafoori et al., 2017). In addition, evidence suggests that big data analytics supports supply chain digitalization and energy efficiency, enabling firms to develop more resilient and environmentally conscious operations (Setiawan et al., 2023).

2. Methodological Approach

This study followed a quantitative and cross-sectional design to examine how Green Supply Chain Management (GSCM) practices affect the environmental and financial performance of manufacturing firms. In line with the objectives presented in the introduction, the model integrates supply chain agility (SCA) and supply chain resilience (SCR) as mediating capabilities, while big data analytics (BDA) is treated as a moderating factor. This approach made it possible to identify statistically significant relationships among the constructs and to understand how managerial capabilities contribute to sustainable performance within the Mexican manufacturing sector.

The study examined a diverse cross-section of Mexican manufacturing firms, spanning industries such as textiles, sports equipment, leather, sugar, and surgical products. This sectoral variety significantly enhanced the representativeness of the sample. To ensure data quality, inclusion criteria required firms to have at least five years of operational history and a minimum workforce of twenty-five employees. Furthermore, respondents were restricted to professionals in positions with direct oversight or knowledge of supply chain processes. Data collection utilized a non-probabilistic convenience sampling strategy conducted via LinkedIn, Facebook, WhatsApp, and email; this digital approach facilitated access to a geographically dispersed pool of professionals in regions where face-to-face surveying was logistically unfeasible. Table 1 shows the demographical description of sampling.

Table 1
Demographical details

Participants	Description	Frequency	Percentage
Gender	Male	174	64.4%
	Female	96	35.5%
Total		270	100%
Age	25 to 30	60	22.22%
	31 to 35	66	24.44%
	36 to 40	83	30.74%
	Above 41	61	22.59%
Total		270	100%

Education	Undergraduate	51	18.88%
	Graduate	131	48.51%
	Postgraduate	88	32.59%
Total		270	100%
Industry Sector	Surgical	19	7.03%
	Textile	35	12.96%
	Sports	22	8.01%
	Leather	31	11.48%
	Sugar	23	8.51%
	Others	140	51.85%
Total		270	100%
Job experience	<5	88	32.59%
	6 > 9	119	44.07%
	10 > 14	40	14.81%
	Above 14 years	23	8.5%
Total		270	100%

A structured questionnaire with a five-point Likert scale was used to measure GSCM practices, environmental and financial performance, agility, resilience, and big data analytics. All items were adapted from validated scales: GSCM and FP from Renaldo & Augustine (2022), EP from Singh et al. (2019), SCA from Ghaderi et al. (2023) and Dubey et al. (2015), SCR from Ghaderi et al. (2024), and BDA from Rachid et al. (2017).

The data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) in SmartPLS 4 (Ringle et al., 2015). This technique was selected because it is suitable for examining complex models with multiple latent variables and performs well when samples are moderate in size or do not meet normality assumptions (Hair et al., 2011; Chin, 1998). Its use aligns with the purpose of this study, which focuses on explaining and predicting how GSCM practices influence organizational performance. The analysis was carried out in two stages. First, the measurement model was evaluated to confirm indicator reliability and validity. Second, the structural model was assessed to determine the strength and significance of the hypothesized relationships, including the mediating effects of SCA and SCR and the moderating role of BDA.

The evaluation of the measurement model focused on verifying the reliability and validity of the indicators. This included examining factor loadings, internal consistency, and convergent validity to ensure that each construct was measured accurately. Once these criteria were met, the structural model was analyzed to assess the relationships among the variables. In this stage, the study examined how SCA and SCR influence the proposed outcomes and tested whether BDA strengthens or weakens the effects of GSCM practices on environmental and financial performance.

3. Empirical findings

The measurement model was evaluated to ensure that the latent constructs were measured reliably and consistently. In line with the recommendations of Mardani et al. (2020) and Kenny (2015), convergent and discriminant validity were examined prior to assessing the structural model.

Convergent validity was assessed using factor loadings, Cronbach's alpha, Composite Reliability (CR), and Average Variance Extracted (AVE), following Hair et al. (2021). All item loadings were above 0.70, alpha values exceeded 0.60, AVE values were higher than 0.50, and CR values surpassed 0.70. These indicators confirm that the constructs meet accepted criteria for convergent validity, as suggested by Murtagh and Heck (2012). Table 2 presents the detailed results.

Table 2
Convergent Validity

	Factor Loading	Cronbach's alpha	Composite reliability	The average variance extracted (AVE)
GSCM2	0.762	0.849	0.892	0.625
GSCM3	0.801			
GSCM4	0.847			
GSCM5	0.819			
EP1	0.807	0.778	0.857	0.601
EP2	0.790			
EP3	0.720			
EP5	0.781			
FP1	0.751	0.788	0.863	0.612
FP2	0.791			
FP4	0.821			
FP5	0.762			
GSCR1	0.772	0.701	0.807	0.515
GSCR3	0.789			
GSCR4	0.725			
GSCR5	0.764			
GSCA1	0.765	0.836	0.884	0.605
GSCA2	0.791			
GSCA3	0.818			
GSCA4	0.713			
GSCA5	0.799			

Note: AVE = Average Variance Extracted; CR = Composite Reliability.

Discriminant validity was supported through the Fornell–Larcker and HTMT criteria, with all values below the 0.90 threshold (table 3). The model also demonstrated acceptable explanatory power (R^2 = 0.661 for EP; R^2 = 0.258 for FP). Effect sizes were small but meaningful, and Q^2 values confirmed predictive relevance. Model fit was adequate (SRMR = 0.07).

Table 3
Fornell-Larcker criterion

	Environmental Performance	Financial Performance	SCA	GSCM	SCR
Environmental Performance	0.775				
Financial Performance	0.348	0.782			
SCA	0.557	0.432	0.778		
GSCM	0.732	0.393	0.552	0.790	
SCR	0.537	0.316	0.354	0.471	0.718

Concerning the Heterotrait-monotrait ratio (HTMT) criterion, the HTMT values varied between 0.432 to 0.895, as displayed in Table 4, and none of them surpassed the threshold of 0.90, as stated by (Henseler et al., 2016).

Table 4
HTMT Approach

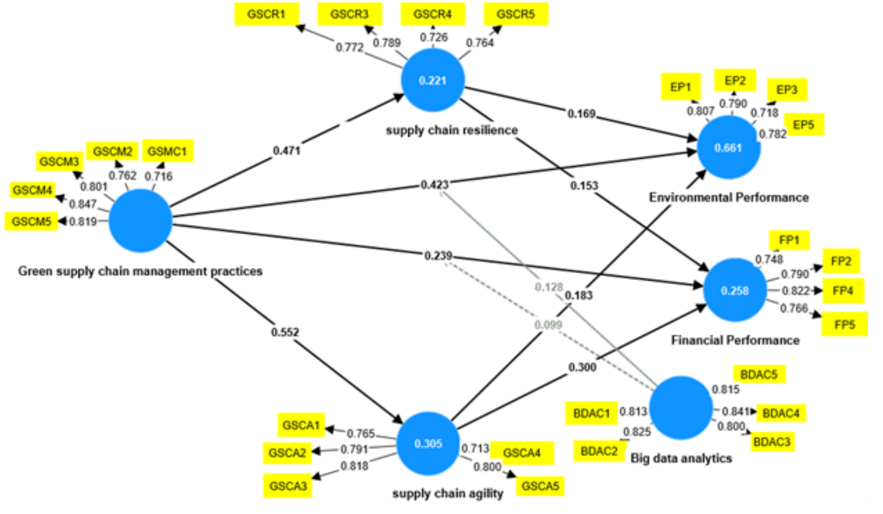
	Environmental Performance	Financial Performance	SCA	GSCM	SCR
Environmental Performance					
Financial Performance	0.443				
SCA	0.688	0.533			
GSCM	0.895	0.479	0.653		
SCR	0.703	0.432	0.454	0.601	

Note: HTMT = Heterotrait-Monotrait Ratio of Correlations. Values below 0.90 indicate discriminant validity.

R^2 values were used to assess the model's explanatory capacity (Barclay et al., 1995). Environmental Performance reached 0.661 and Financial Performance 0.258. Thus, GSCM, SCA, and SCR jointly explain 66.1% of the variance in EP and 25.8% in FP, exceeding the minimum threshold of 0.10 suggested by Hair et al. (2021). Diagram 1 illustrates these values. Therefore, Hair et al. (2021) mentioned that to consider the adequacy of the variance explained by a specific endogenous construct, the R-squared (R2) values should either equal or exceed 0.10.

Diagram 1 illustrates the proposed relationships among green supply chain management practices, supply chain agility, supply chain resilience, and firm performance, highlighting the mediating and moderating mechanisms examined in this study.

Diagram 1
Structured modelling analysis



Effect sizes ranged from 0.055 to 0.099, indicating small contributions of the predictor variables, based on Cohen's (2013) benchmarks. Table 5 presents these results.

Table 5
Quality of the structural model

	Q^2	F^2	
		Environmental Performance	Financial Performance
Supply chain agility	0.294	0.063	0.076
SCR	0.209	0.099	0.055

All Q^2 values were greater than zero, indicating predictive relevance. Model fit was assessed using SRMR, which yielded a value of 0.07, below the recommended 0.08 threshold, suggesting acceptable fit.

The structural model was assessed through the path coefficients and their significance levels (table 6). Using the bootstrapping procedure proposed by Efron (1992), we evaluated the t-values and p-values for each hypothesized relationship. As shown in Table 6, GSCM practices showed significant positive effects on Environmental Performance ($\beta = 0.423$, $t = 7.696$, $p < 0.001$) and Financial Performance ($\beta = 0.239$, $t = 2.309$, $p < 0.05$). GSCM was also strongly associated with both Supply Chain Agility ($\beta = 0.552$) and Supply Chain Resilience ($\beta = 0.471$).

Table 6
PLS structural model

Hypothesis	B	(STDEV)	T value	P values
GSCM practices -> Environmental Performance	0.423	0.055	7.696	0.000
GSCM practices -> Financial Performance	0.239	0.103	2.309	0.021
GSCM practices -> SCA	0.552	0.066	8.330	0.000
GSCM practices -> SCR	0.471	0.059	8.002	0.000
SCA -> Financial Performance	0.300	0.090	3.321	0.001
SCA -> Environmental Performance	0.183	0.065	2.816	0.005
SCR -> Environmental Performance	0.169	0.041	4.160	0.000
SCR -> Financial Performance	0.153	0.065	2.349	0.019
GSCM practices -> SCA -> Financial Performance	0.166	0.059	2.805	0.005
GSCM practices -> SCA -> Environmental Performance	0.101	0.043	2.377	0.018
GSCM practices -> SCR -> Environmental Performance	0.080	0.022	3.638	0.000
GSCM practices -> SCR -> Financial Performance	0.072	0.033	2.193	0.029
Big data analytics x GSCM practices -> Environmental Performance	0.128	0.033	3.838	0.000
Big data analytics x GSCM practices -> Financial Performance	0.099	0.054	1.824	0.068

In turn, SCA and SCR positively influenced Environmental and Financial Performance, and all paths were statistically significant ($p < 0.05$). These results confirm the central role of both capabilities in strengthening sustainability outcomes within manufacturing firms.

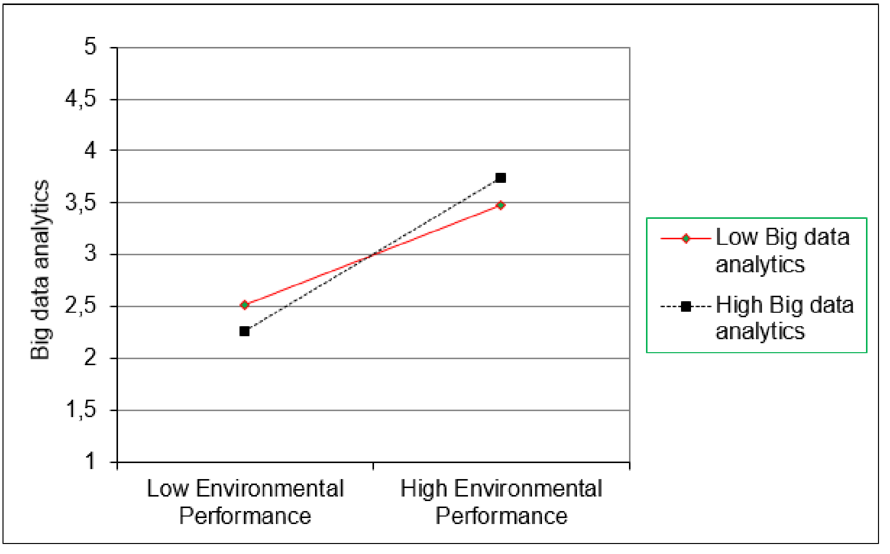
3.5 Mediation and Moderation Analysis

The mediation tests showed that both SCR and SCA transmit part of the influence of GSCM practices to performance outcomes. SCR served as a mediator between GSCM and EP (**β** = 0.080, t = 3.638) and between GSCM and FP (**β** = 0.072, t = 2.193). SCA also showed significant mediation effects for EP (**β** = 0.101, t = 2.377) and FP (**β** = 0.166, t = 2.805). Overall, the results confirm that agility and resilience help explain how green practices translate into improved performance.

Regarding moderation, BDA strengthened the relationship between GSCM and EP (**β** = 0.128, t = 3.838), while its effect on the link between GSCM and FP was not statistically significant (**β** = 0.099, t = 1.824). These results suggest that digital analytics capabilities mainly enhance environmental outcomes rather than immediate financial gains.

Graph 1 illustrates the moderating role of big data analytics in the relationship between green supply chain management practices and firm performance. The diagram shows that big data analytics strengthens the effect of green supply chain management on environmental performance, indicating that firms with higher analytical capabilities are better able to translate green practices into improved environmental outcomes. In contrast, the moderating effect of big data analytics on the relationship between green supply chain management and financial performance is weaker and not statistically significant, suggesting that the benefits of data-driven capabilities are more evident in environmental improvements than in immediate financial gains.

Graph 1
Moderation Analysis



This study examined how GSCM practices influence environmental and financial performance in Mexican manufacturing firms. The findings confirm that green practices enhance both outcomes and that agility and resilience operate as mechanisms that convert GSCM initiatives into measurable benefits. These results extend prior research by demonstrating that dynamic capabilities strengthen the effects of GSCM in an emerging economy.

Agility and resilience showed consistent positive effects on performance, reinforcing previous studies that highlight their strategic value. The moderating role of big data analytics was significant for environmental outcomes, suggesting that digital capabilities help firms optimize green initiatives before generating direct financial returns. Overall, the study contributes by integrating GSCM, dynamic capabilities, and digital analytics into a unified model that helps explain how firms improve sustainability in competitive environments

4. Conclusion

This study shows that GSCM practices improve environmental and financial performance when supported by agility, resilience, and data-driven capabilities. The results provide empirical evidence from Mexico and highlight how dynamic capabilities help firms transform sustainability initiatives into measurable outcomes.

Theoretical contributions arise from integrating institutional theory, stakeholder theory, and the dynamic capability view to explain how external pressures and internal resources interact in shaping sustainable performance. The findings also reveal that big data analytics strengthens environmental outcomes, suggesting that digital tools enhance the implementation of green practices.

Practically, the study emphasizes that agility and resilience are long-term strategic capabilities that help firms manage uncertainty, adapt to disruptions, and strengthen competitiveness. Future research could incorporate longitudinal analyses or international comparisons to deepen understanding of how green supply chains evolve over time.

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